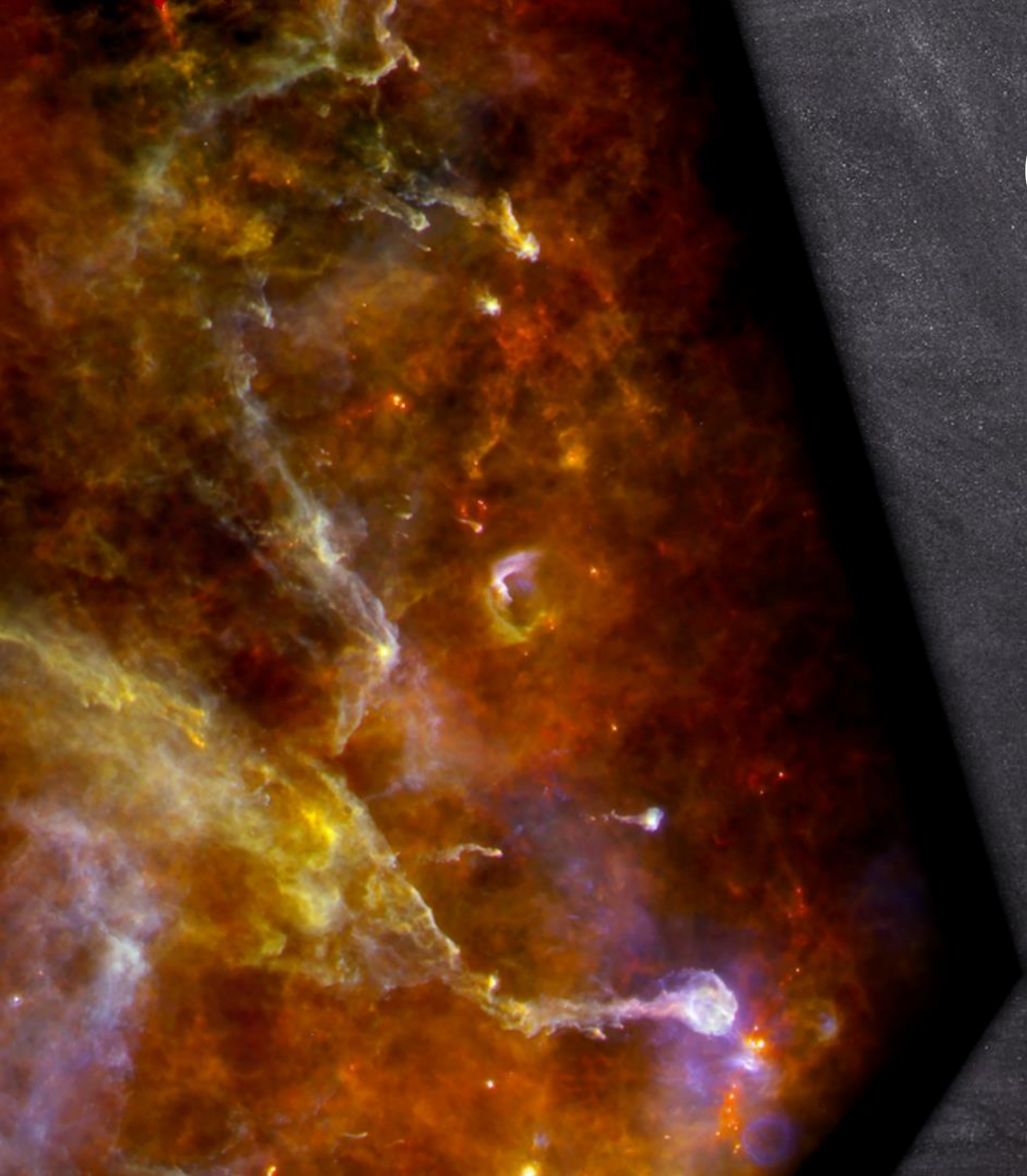

CTA Massive Star Clusters

Cyg OB2 models for the new data challenge

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Outline

- Additional CR models for massive star clusters
    - Application to Cyg OB2
- CR distribution function
- Gamma ray flux
- Radial properties for the gamma emission
- Conclusion

CR accelerated by MSC

We use the model developed by Morlino et al. (2022) of CR accelerated at the winds' termination shock from MSC to obtain the CR distribution function.

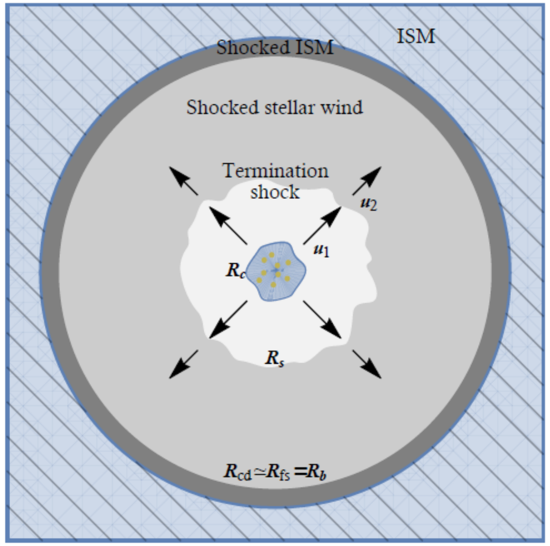
$$\begin{cases} f(r < R_{TS}; E) = f_{TS}(E) \cdot exp\left[-\frac{u_1(R_{TS} - r)}{D_1} \right] \\ f(R_{TS} < r < R_b; E) = f_{TS}(E)\Gamma_1 + f_{gal}(E)\Gamma_2 \\ f(r > R_b; E) = f(R_b; E)\frac{R_b}{r} + f_{gal}(E)\left(1 - \frac{R_b}{r}\right) \end{cases}$$

Where Γ_1 and Γ_2 are function depending on D_2, D_{ism}, u_2, R_{TS} and R_b

The distribution of injected particles is modeled as:

$$f_{TS}(E) = k\left(\frac{E}{E_0}\right)^{-\alpha} exp\left[-\left(\frac{E}{E_{coff}}\right)^{\beta} \right]$$

In the full solution, the cut-off shape is connected to the diffusion coefficient (i.e. to the turbulence type)



Parameters for Cygnus OB2

$L_w = 2 \times 10^{38}$ erg/s ; $dM/dt = 10^{-4} M_{sun}$/yr ; $d_{OB2} = 1400$pc

$u_1 = 2500$ km/s ; $u_2 = u_1/4$; $\rho_H = 10/cm^3$; $t_{age} = 3$Myr

$$R_{TS} = 0.7 \cdot L_w^{-1/5} \dot{M}^{1/2} u_1^{1/2} \rho_H^{-3/10} t_{age}^{2/5} \simeq 16pc$$

$$R_b = 0.76 \cdot \left(\frac{L_w}{\rho_H}\right)^{1/5} t_{age}^{3/5} \simeq 98pc$$

- Previous simulation (updated in the las months) were obtained using a Kolmogorov like turbulence (K41 model)

$$D_{K41}(E) = \frac{1}{3}\beta c r_L^{1/3} L_c^{2/3}$$

- We developed now also models with a Kraichnan and Bohm like turbulence

$$D_{Kra}(E) = \frac{1}{3}\beta c r_L^{1/2} L_c^{1/2} \quad ; \quad D_{Bohm}(E) = \frac{1}{3}\beta c r_L$$

- These additional models can be used as different possible realization for known MSC in the next DC

CR distribution

- Different type of turbulence produces diverse radial distributions
- Energy dependent morphology
- The plots only show the distribution of accelerated CR (<u>no contribution of CR sea penetrating the bubble</u>).

For each model we can build several realization using different spectral parameters of injected particles.

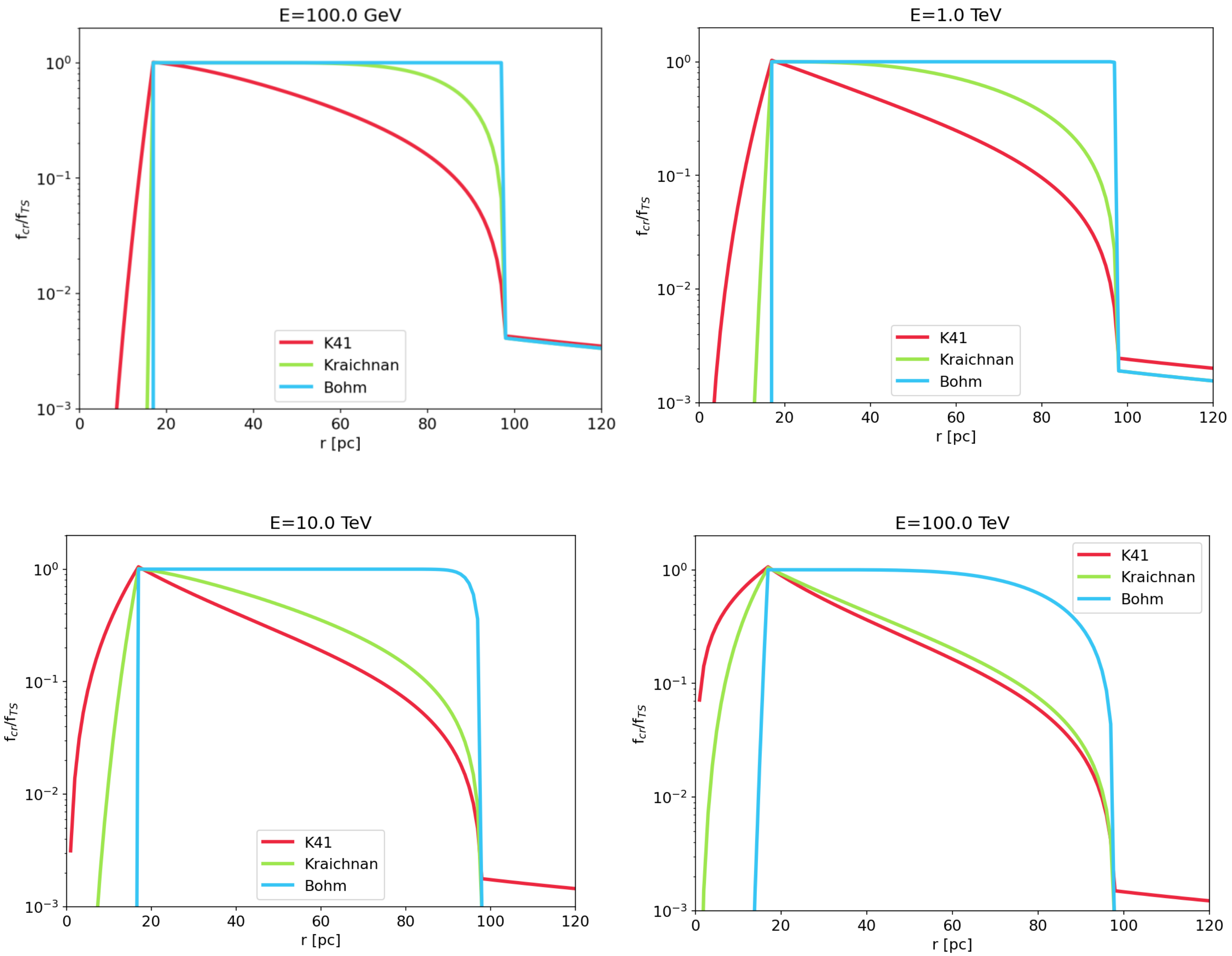
- K41: $\varepsilon=0.04$, α=[2.1, 2.0, 2.2], E_{max}=[0.09, 0.5, 3] PeV
- Kra: $\varepsilon=0.02$, α=[2.1, 2.0, 2.2], E_{max}=[0.43, 0.17, 1.61] PeV
- Bohm: $\varepsilon=0.017$, α=[2.3, 2.2, 2.4], E_{max}=[3, 1.79, 6.43] PeV

The maximum energy is linked to the value of the mass loss ratio and the wind luminosity (or the wind speed)

$$D_1(E_{max})/v_w \approx R_{TS}$$

For the Kraichnan and Bohm case the maximum energies are calculated considering three possible values of wind luminosity

(Lw=[1, 2, 5.5]x10^{38} erg/s for CygOB2)

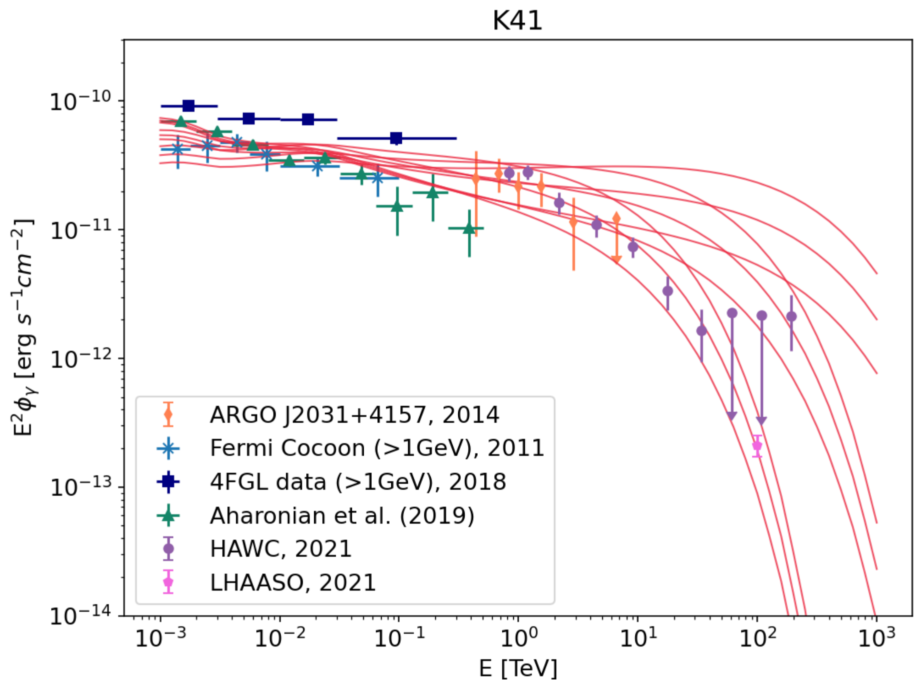


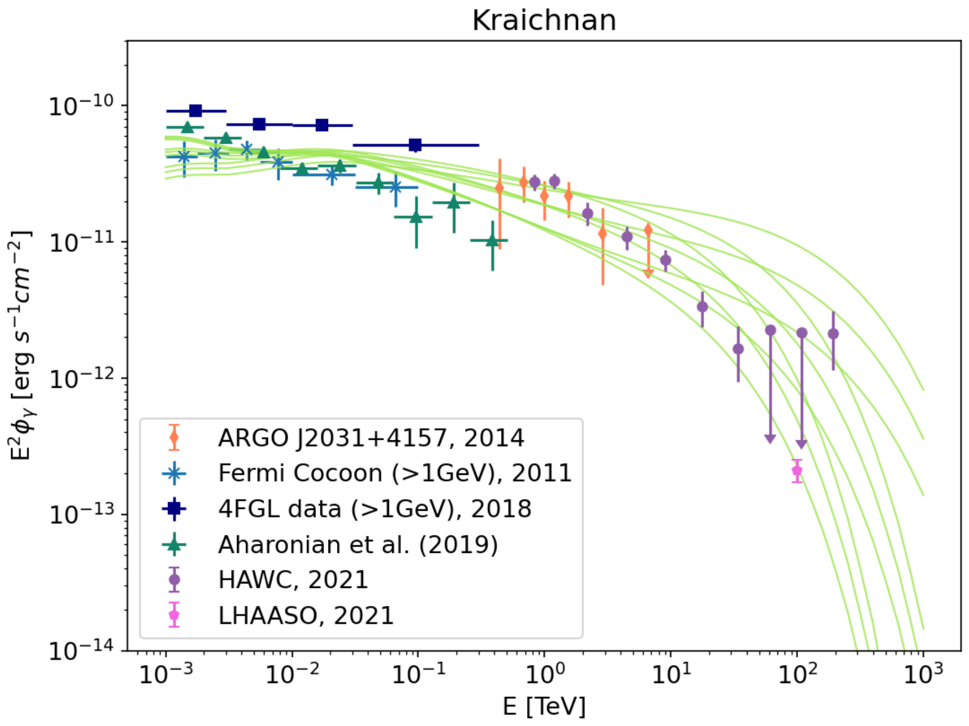
Gamma spectra

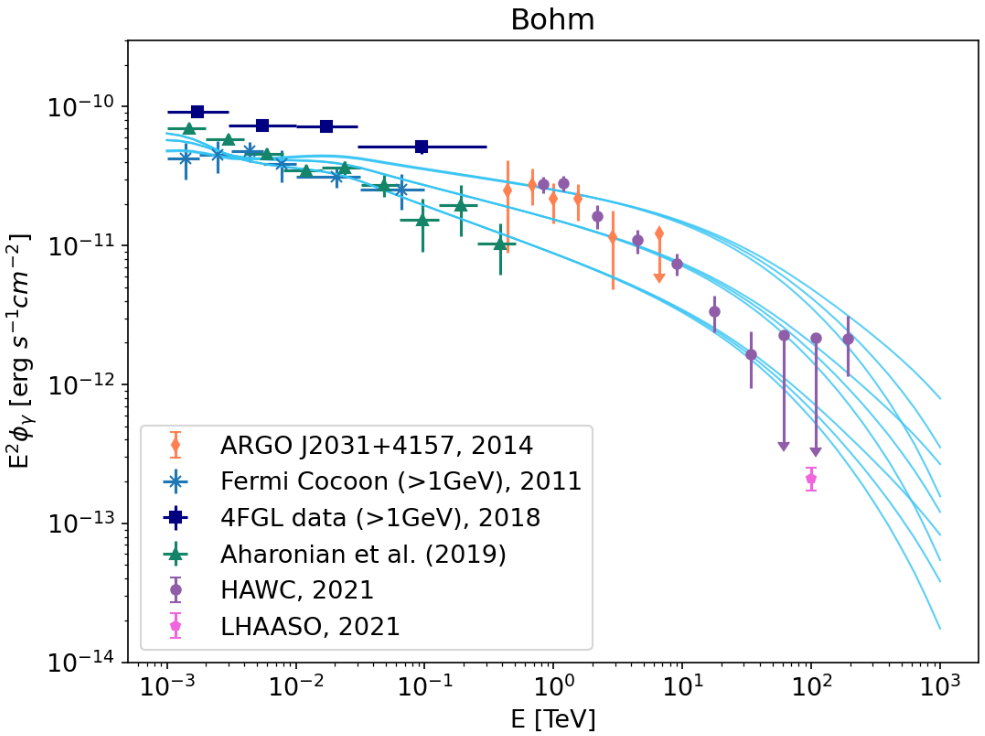
Target gas used:

- H_2: 12CO(J=1-0) CfA (Dame et al, 2001) Lowres. + NRO (Takekoshi et al, 2019) Highres. Xco=1.68 10^{20} mol. cm-2 K-1 km-1 ; -20km/s<v<20km/s
- HI: 21cm from CGPS (Taylor et al, 2003). T=150°K ; -20km/s<v<20km/s

$$\phi_\gamma(l,b;E_\gamma) = \iint \frac{c\,\Omega r^2}{4\pi r^2} n_{\rm gas}(l,b,z)\, f_{\rm CR}(l,b,z;E_p)\, \frac{d\sigma(E_p,E_\gamma)}{dE_p} dE_p dz$$

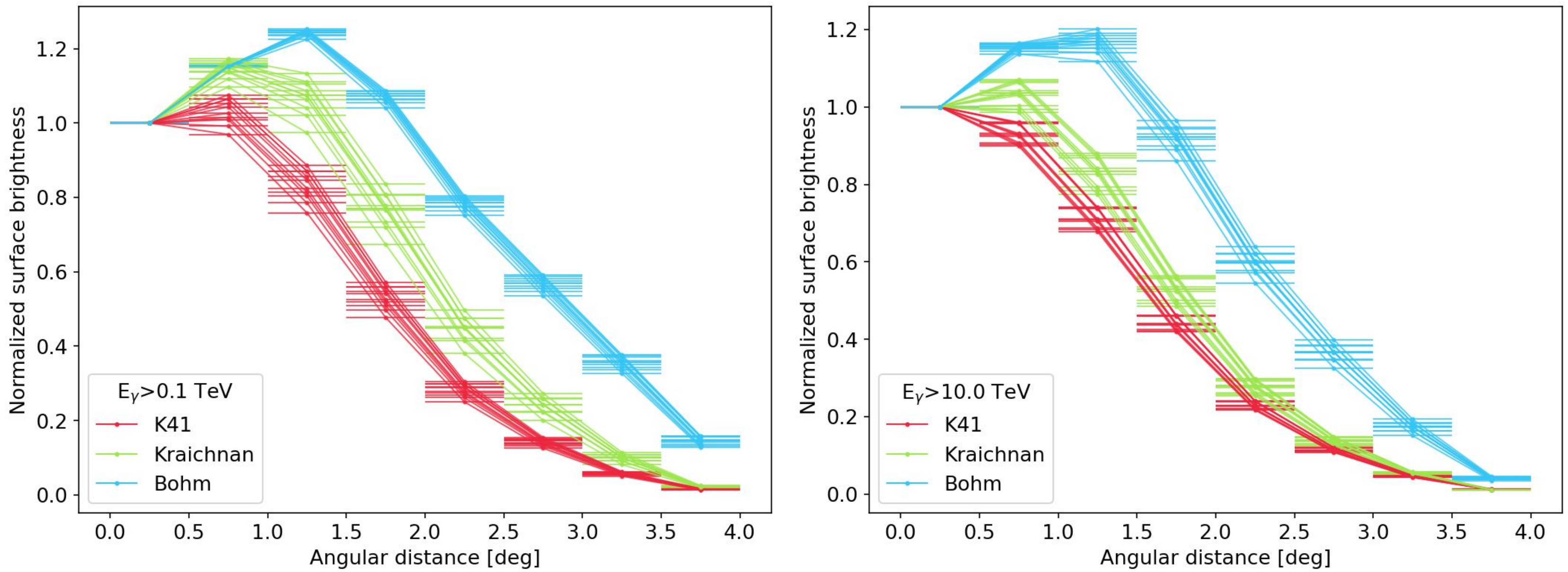


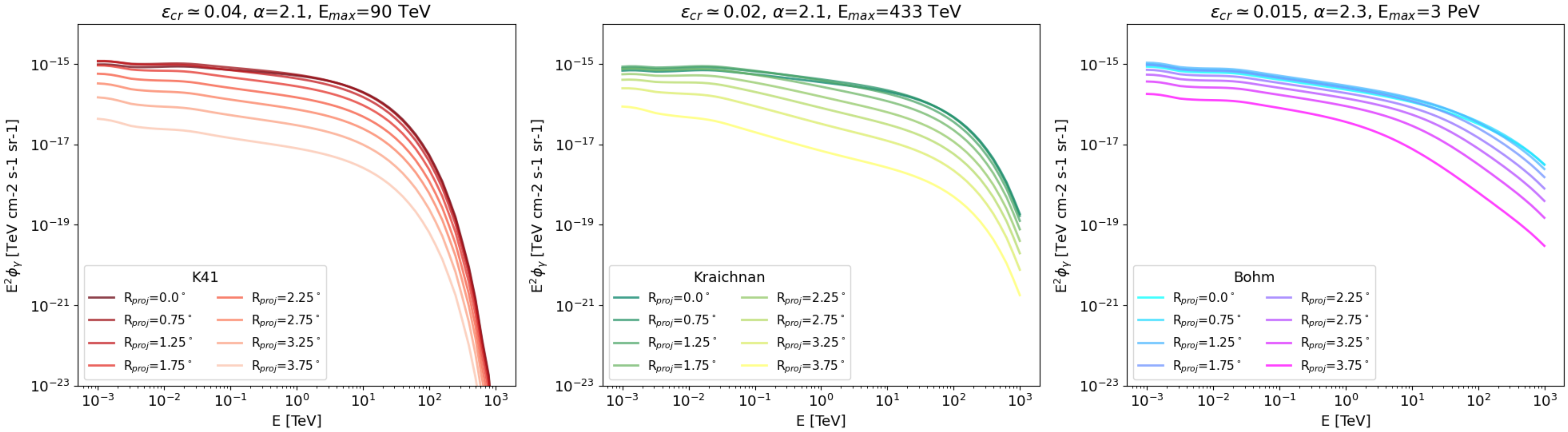




Radial properties

Surface brightness and spectra in 8 rings of width 0.5° (up to 4° that is ~R_{bubble})





Conclusion

- For the data challenge, we need to produce different realization for every objects:
  - In order to have a better variety, we can consider several realizations of 3 different model of turbulence propagation of CR
  - Considering 9 different spectral parameters for the spectrum of injected particles we have a total of 27 realizations.

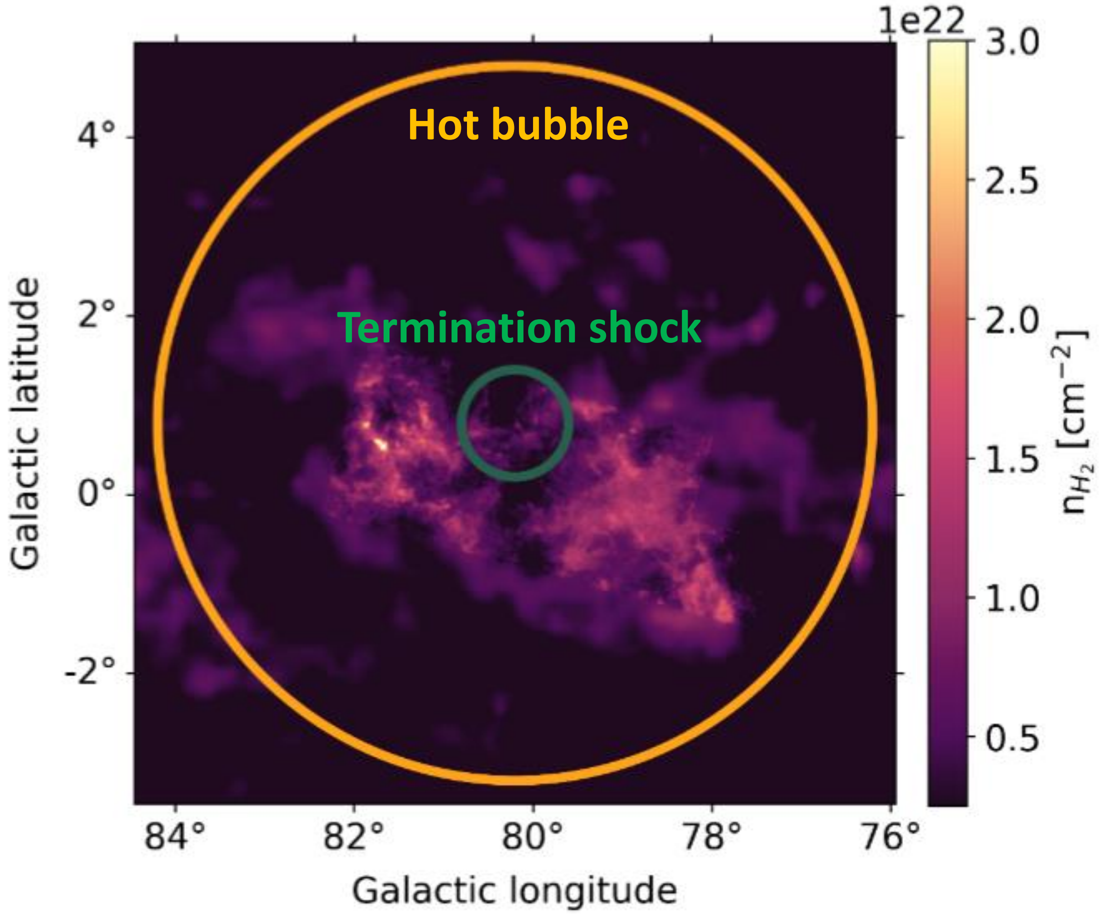
- To do: run the same models for Wd1 and Wd2

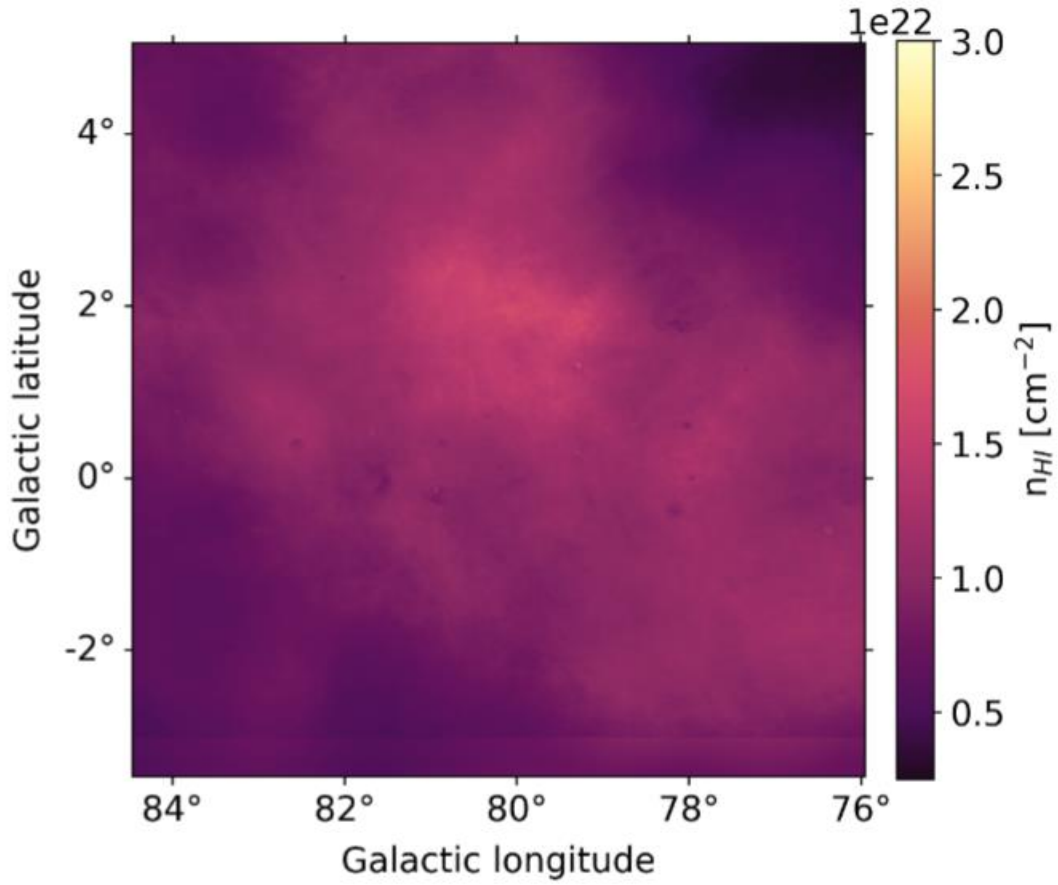
Backup Slides

OB2 - Gas distribution

H_2: 12CO(J=1-0) CfA (Dame et al, 2001) Lowres. + NRO (Takekoshi et al, 2019) Highres.
(Xco=1.68 10^{20} mol. cm-2 K-1 km-1 ; -20km/s<v<20km/s)

HI: 21cm from CGPS (Taylor et al, 2003)
(T=150°K ; -20km/s<v<20km/s)





Profile comparison